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TITLE: TEN YEARS OF VELA X-RAY OBSERVATIONS

AUTHOR(S): JAMES TERRELL and WILLIAM C. PRIEDHORSKY

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SANTA CRUZ, CALIFORNIA

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

TEN YEARS OF VELA X-RAY OBSERVATIONS

James Terrell and William C. Priedhorsky
Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT: The Vela spacecraft, particularly Vela 5B, produced all-sky X-ray data of unprecedented length and completeness. The data led to the discovery of X-ray bursts and numerous transient outbursts. Recent re-analysis has put the data in the form of 10-day skymaps covering a 7-year period, which have led to the discovery or confirmation of a number of long-term periodicities, and have made possible a time-lapse movie of the X-ray sky.

One spacecraft, Vela 5B, monitored the X-ray sky for more than 10 years, producing all-sky data for a period of unprecedented length. The Vela spacecraft, watching for nuclear tests in space, were among the first to be capable of X-ray astronomy.[1] Vela 5B observed the sky with collimated NaI photomultiplier detectors, sensitive to 3-12 keV X-rays, from 26 May 1969 to 19 June 1979. The detectors scanned along a great circle at right angles to the earth-spacecraft axis as the spacecraft spun with a nominal period of 64 seconds. The very large orbital radius of 118000 km corresponds to an orbital period of 112 hours, so that the entire sky was observed in 56 hours, half of the orbital period. Although the detectors had a sensitive area of only 27 cm^2, they were quite adequate for observations of many X-ray bursts,[2,3] a few gamma-ray bursts[4], and numerous transients.

The first and brightest of these transient sources was Cen X-4, first observed--as an X-ray burst[5]--on 7 July 1969. Its time history, seen in Fig. 1, shows that it rose very rapidly to an intensity considerably brighter than that of Sco X-1 and remained bright for about 3 months[1] (each Vela count corresponds to $\sim 4\times10^{-10}$ $ergs/cm^2$, and to ~25 Uhuru counts). Cen X-4 then vanished for 10 years, not reappearing until May 1979, at which time it was possible to identify it optically.[6] The position ($\ell = 332.24^\circ$, $b = 23.88^\circ$) agreed well with that calculated[7] for the earlier outburst.

The entire set of Vela data has been reprocessed in the last few years, with recalibration of viewing angle and correction of some earlier problems in spacecraft data and in analysis. One of the results has been a set of 10-day skymaps for the 7-year period during which data acquisition was most complete (May 1969-June 1976). These have recently been put into the form of a movie in color[8], showing in time-lapse fashion the changes in the X-ray sky map as seen by Vela 5B. Several examples of these skymaps have been published.[4,9,10] Figure 2 shows the galactic center portion of the 1969 skymap, with Cen X-4 prominent near Sco X-1, normally the brightest source. These skymaps represent the average counting rate above background in each $2^\circ \times 2^\circ$ area of the sky, by means of symbols of varying intensity (and color, in the movie). Each point source is spread over an appreciable area of the skymap because of the $6.1^\circ \times 6.1^\circ$ resolution

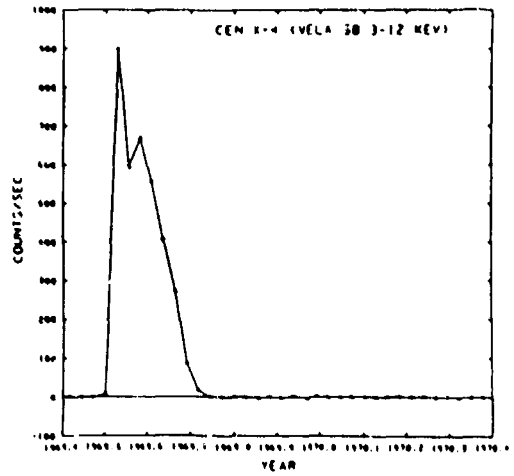

Fig. 1. Time history of the 1969 Cen X-4 transient outburst.

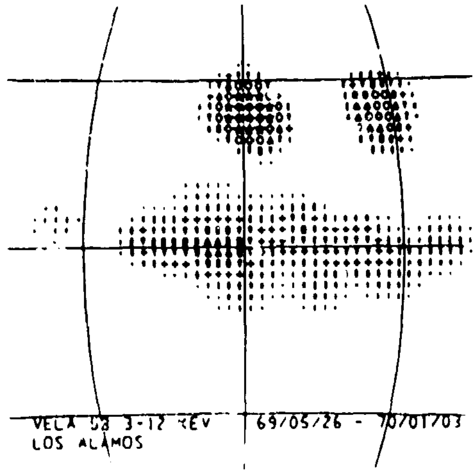

Fig. 2. Galactic center portion of the 1969 Vela 5B X-ray skymap.

(FWHM) of the collimator. An additional angular spread is introduced by the 1-second time resolution of the data.

Many sources, such as Cen X-4, are well-separated from others, and it is not difficult to evaluate the time history and accurate position of such sources from these skymaps. In other cases it is necessary to use a least-square fitting procedure to separate the data from sources which are only a few degrees apart. Such techniques have already resulted in long-term time histories of a number of X-ray sources.[11-13] In a number of cases new periodicities have been found, such as the 294-day period[11] of Cyg X-1 and the 132.5-day period[13] of GX304-1. In other cases previously suggested periodicities, such as the 111-day period[12] of A0535+26 and the 41.5-day period[13] of GX301-2 have been confirmed, and other periods have been ruled out. A number of previously unknown transient outbursts have been found in the Vela data. There was, for example, a bright transient outburst[13] from 4U1145-61 in April 1973, at a time when other spacecraft with all-sky X-ray capability were not functioning.

An even more interesting transient outburst occurred in June 1973 from a previously unknown source in Camelopardus[9], V0332+53, which was also observed only by Vela 5B. This source, as may be seen in Figure 3, rose gradually to an intensity of 1.4 Crab and then died away, lasting for a total of 3 months. The slow rise is quite different from the more typical outburst of Cen X-4, seen in Fig. 1. The position of this new source, at galactic coordinates 146.1°, -2.0°, is known to an uncertainty of ~0.2°, and is still being refined. This hard X-ray source gave clear indications of rapid fluctuations on a short time scale, which are under investigation.

A number of extragalactic sources are also quite evident in the Vela data. One of the most interesting of these is the nearest active galaxy, Cen A (NGC 5128). During the period 1973-1975 the nucleus of this galaxy produced much more X-ray flux than usual and showed considerable variability.[14] The Vela 5B data give evidence

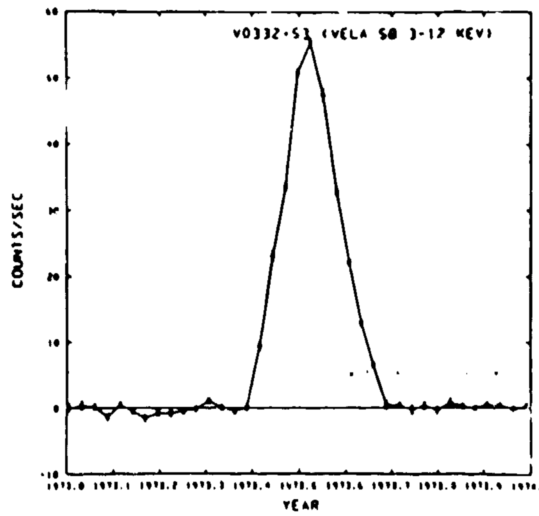

Fig. 3. Time history of the 1973 transient outburst of V0332+53.

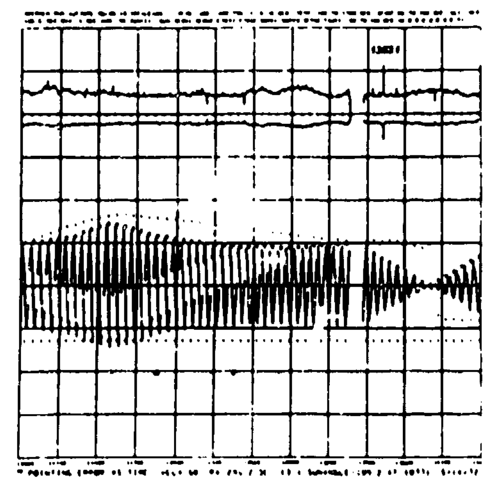

Fig. 4. Vela X-ray data showing detection of a gamma-ray burst.

of a number of rapid changes in intensity during this active period, often occurring in less than 10 days.[15] Since the X-ray emission often reached the level of 5×10^{42} ergs sec^{-1}, the source of X rays is obviously both small and massive.

Thus the 10-day skymaps produced from the Vela 5B data have led to a number of important results. The full data are much more complete, with 2 energy channels, 1-second time resolution, and observations of individual sources every 64 seconds. By means of this capability Vela 5A and 5B recorded brief outbursts from a number of X-ray sources, leading to the discovery of the phenomenon of X-ray bursts.[2,3,5] This was also found independently[16] from observations by the Astronomical Netherlands Satellite.

A complete re-examination of the Vela X-ray burst data has recently been undertaken. The use of more stringent criteria for acceptance of burst data, such as requiring that the burst appear convincingly in both energy channels and that the data be free of charged-particle effects, has eliminated most of the large number of possible bursts observed.[17] The convincing bursts are mostly from known sources, and particularly from 4U1608-52, the Norma burst source. A number of large bursts not previously reported have been found to come from this source, which is evidently one of the nearest burst sources, or at least one of the most intense observed.

A few large bursts per year do not come from known burst sources. Some of these are likely to be the X-rays associated with gamma-ray bursts. Two of these X-ray bursts have been identified with known gamma-ray bursts,[4] one (GB720514) at galactic coordinates $\ell = 129^{o}$, $b = 39^{o}$, and the other (GB740723) from an area near the Small Magellanic Cloud (the direction of this burst is known only from the X-ray data). This is about the number of such detections expected, considering the viewing area of the Vela collimator and the fraction of time devoted to data acquisition from the spacecraft. The counting rate of the Vela X-ray counter during one of these gamma-ray burst detections (GB720514) is shown in Figure 4, which includes one hour of observation. The 4-second average of counting rates is shown near the top of the figure, with the total counting rate from both channels plotted in the positive sense, and the counting rate from the 6-12 keV channel plotted negatively, from the same line. Other spacecraft data shown indicate normal operation. The very obvious hard peak at 13631 UT (time receive') is similar to many other X-ray bursts, but comes from the direction and at the time of a known gamma-ray burst. There are also indications of weaker recurrences of X rays from the same source.[4]

Thus the Vela X-ray data have proved to be important in the discovery of bursts, transients, and periodicities, indicating the value of all-sky monitoring capability over an extended period of time, even with detectors of less than ideal sensitivity. This work was supported by the U.S. Department of Energy and by the Department of Defense.

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